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STUDIES ON IMPROVING THE DISTRIBUTION OF HYDROCYANIC ACID IN CITRUS FUMIGATION

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In field fumigations of citrus trees for control of the California red scale (*Aonidiella aurantii* (Mask.)) over a period of years, members of the Whittier, Calif., laboratory have observed that the concentration of hydrocyanic acid varies at different locations in tent-covered trees. To control this scale most effectively with fumigation, good distribution of the gas is necessary. Poor distribution means locations of high survival, which may become heavily infested in a short time. This is most likely to be the case in groves with strains that are resistant to this fumigant. The importance of uniform distribution was recognized by Gray and Kirkpatrick (3) and Pratt *et al.* (4). Extensive studies were made to determine whether the vaporizer applicators in general use could be improved or a better applicator developed. This paper reports the results of these studies.

Materials and Methods

In special preliminary tests the vaporizer nozzle was properly located under the edge of the tent with the outlet directed toward the center of the tree, and other controllable factors were carefully regulated. Subsequent tests were made during the course of regular commercial fumigations. The two makes of vaporizers in general commercial use [2] were used. When they were both used in the same test, the pumps were carefully adjusted to deliver equal amounts of liquid hydrocyanic acid. Unless otherwise stated, a 20-cc. schedule was used, that is, 20 cc. of liquid hydrocyanic acid per unit. A unit is about 100 cubic feet for trees of 700 to 900 cubic feet, less for smaller trees, and more for larger ones, so that the average concentrations are roughly uniform for trees of all sizes. The tents were usually made of 8-ounce Army duck.

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2/ Developed by the American Cyanamid Co. and E. I. du Pont de Nemours and Co., Inc.

The gas distribution was determined by sampling selected locations under the tents. In some tests gas samples were taken from eight locations—about 6 feet from the ground 2 to 3 feet inside the tent at each of the four cardinal directions, 2 to 3 feet from the ground (low) midway between the tree trunk and the tent on the east and west quadrants, and 2 to 3 feet from the top of the tent to the north and south of the tree center. In other tests gas samples were obtained from only four locations—about 6 feet from the ground 2 to 3 feet inside the tent on the east and west quadrants, 2 to 3 feet from the ground (low) midway between the tree trunk and the tent on the south, and 2 to 3 feet from the top north of center. The samples were drawn as described by Fulton _et al._ (_1_), except that Tygon tubing was used.

In the preliminary tests the exposures were usually for about 5 minutes and the same trees were frequently fumigated successively with different equipment. The coefficient of variation in concentration (standard deviation x 100/average concentration) was usually calculated as a measure of the variability of the gas distribution. A small coefficient of variation indicates good distribution and a large one poor distribution. Mortality counts, when made, were usually based on 100 scales from each of four locations in each tree.

Application With Standard Commercial Vaporizers

To determine the distribution of hydrocyanic acid with the vaporizers in general use, 20 relatively open lemon trees were fumigated on 5 nights. Gas samples were taken from 8 locations under each tree ½, 2½, and 5 minutes after release of the gas. The trees varied in size from small to moderately large (10 units to 24 units) and had average foliation. The nozzle of the applicator was properly placed under the west side of each tree. The average concentration at each sampling location is given in table 1.

Table 1.—Average concentrations (milligrams per liter) of hydrocyanic acid at selected locations under medium-foliated lemon trees at designated intervals after release of the gas from the west

Location	½ minute	2½ minutes	5 minutes
6 feet above ground:			
North	4.60	3.44	2.70
East	3.83	3.30	2.56
West	1.45	2.04	1.90
South	2.65	2.49	2.24
Low:			
East	4.26	3.30	2.49
West	1.21	1.94	1.82
Top:			
North	3.51	3.19	2.48
South	2.76	2.56	2.24

The concentrations were low on the side of release (west) near the ground and at the 6-foot level. On the side opposite the nozzle the concentrations were comparatively high at the same levels.

Gas-distribution studies of commercial fumigations were also made in densely foliated lemon trees in connection with studies of scale mortality. Gas samples were taken from 4 locations in 12 trees and scale samples from 4 locations in 16 trees. The fumigation schedules used were 22 and 24 cc. per unit. The gas was released from the east side of the tree. The average concentrations for 45 minutes at the 6-foot-east, 6-foot-west, low-south, and top-north sampling positions were 0.86, 1.28, 0.87, and 1.14 mg. per liter, respectively. In general the concentrations on the east were low at the beginning and throughout an appreciable part of the exposure period, whereas those on the west, opposite the nozzle, were comparatively high during most of the exposure period. The low concentrations on the south were probably due to a tendency of the operator to go beyond the mid-point and put the nozzle under the southeast quadrant. The kill of scales in the second-molt stage at the 6-foot-east, 6-foot-west, low-south, and top-north positions was 58.3, 77.1, 51.2, and 76.6 percent, respectively. These data show the correlation between gas concentration and scale mortality. Similar results have been obtained in the fumigation of orange trees with differing amounts of foliation.

In the fumigation of the grove in which the foregoing experiment was carried out, it is the practice to treat the trees from the east side while moving down the rows from north to south. Population counts made in the grove corroborated the results obtained in the experimental fumigations. The scale population was heaviest on the east aspect of the trees, where the gas concentrations were lowest, and lightest on the west side, where they were highest. The data suggest the desirability of releasing the gas from opposite sides of the trees in alternate fumigations.

Tests were made with the vaporizer to determine the effect of foliage density on distribution of hydrocyanic acid. Fourteen dense orange trees and an equal number of open lemon trees were fumigated in special tests. To get information on the distribution in the absence of a tree, 14 fumigations were also made in 2 tree forms. The tree forms were equivalent in size to a medium-sized tree and approximately the same size as the orange and lemon trees used. Gas samples were taken $\frac{1}{2}$ minute and $2\frac{1}{2}$ minutes after release of the gas. The average coefficients of variation in the concentrations are given in table 2. It is evident that foliage density influences the distribution of hydrocyanic acid. In a tree form containing no tree good distribution was almost immediate. The data indicate that pruning out of interior growth from the trees would aid in getting better distribution of hydrocyanic acid.

Table 2.—Effect of tree density on the distribution of hydrocyanic acid

Tree density	Coefficient of variation in concentration (percent) at indicated interval after release	
	½ minute	2½ minutes
Dense	92.1	46.0
Open	52.2	23.0
Form (no tree)	7.5	5.4

Release of Gas From Two Locations

In special tests in which half the hydrocyanic acid was released with a standard vaporizer from one point and half from the opposite point under the trees, the gas distribution was much more nearly uniform than when it was released from one place. Tests were made in three groves, in cooperation with commercial fumigators, to determine whether in practical operation the use of this procedure would improve the distribution of the gas. Gas samples were taken at 4 locations from each of 16 trees in each category. The average coefficient of variation determined from the samples taken after 1/2 minute was 91.9 percent when the gas was released at one point and 64.4 percent when it was released from two points. For the samples taken 2 1/2 minutes after release the respective coefficients were 33.1 and 36.9 percent.

These data indicate that release of liquid hydrocyanic acid from two points beneath the tents instead of one would not improve gas distribution sufficiently to justify the extra labor and time required to reset the nozzle. Furthermore, protective stupefaction might increase with consequent decreased kill.

Standard Vaporizer Nozzle With a Baffle Added

In several fumigations lifting the nozzle of the vaporizer to direct the gas upward greatly improved the distribution. This experience led to the development of a mechanical device, or baffle, for changing the direction of the discharge of gas. The device consisted of a flat piece of sheet metal 2 by 2½ inches attached to the vaporizer nozzle on a hinge. The baffle position could be changed manually by means of a cable extending through a conduit along the gas hose. By pulling the cable the operator drew the baffle in front of the nozzle opening, causing the gas to go upward and outward instead of across to the opposite side of the tree. In operation the baffle was pulled into place after the hydrocyanic acid was pumped into the vaporizer. It was estimated that a little over half the hydrocyanic acid had escaped from the hose before

the baffle position was changed.

Eleven medium-sized, dense orange trees were used in special tests to compare the baffle nozzle with the standard nozzle from the standpoint of gas distribution. The same trees were treated with each nozzle. Tests were made on three nights, and gas samples were taken from four locations. The average coefficients of variation determined from the samples taken ½ minute after release of the gas were 84.8 percent for the standard nozzle and 44.8 for the baffle nozzle; for the samples taken 2½ minutes after release the respective coefficients were 38.0 and 24.4 percent.

The distribution was greatly improved by changing the direction of the stream of hydrocyanic acid during part of the release period, so that the lowest concentration was not always close to the nozzle and the highest was not always on the opposite side of the tree. However, in the field the moving parts of the baffle nozzle were found to catch on vegetation or the tents and retard operations. It is probable that a streamlined unit could be constructed that would overcome this disadvantage.

Nozzle With Outlets 2 Feet Apart

Standard nozzles were modified in many ways in an attempt to increase the concentration of gas near the nozzle and decrease it on the opposite side of the tree. Many nozzles with more than one outlet releasing the gas in different directions were devised and tested before one was found that improved distribution. Multiple-outlet nozzles with the outlets not more than 3 inches apart failed to improve distribution. With two or more outlets not more than 3 inches apart the gas tended to be drawn into a single stream. Further tests showed that the outlets should be at least 2 feet apart.

Special field tests were made to compare the gas distribution by a special nozzle having outlets 2 feet apart with that by a standard nozzle. The special nozzle differed from the standard only in having an extra outlet 2 feet back of the regular one. The extra outlet was simply a crosswise slot 3/32 inch wide halfway through a 3/4-inch pipe coupling. The gas escaped at a right angle to the coupling through 180°. In the tests 16 orange trees were treated with each nozzle arrangement. The trees were dense with foliage and medium in size. Gas samples were taken from four locations and the tests were made on five nights. The average coefficients of variation determined from the samples taken ½ minute after release of the gas were 84.7 percent for the standard nozzle and 54.0 percent for the special nozzle. For the samples taken 2½ minutes after release the respective coefficients were 47.9 and 32.3 percent.

The distribution of hydrocyanic acid was better when release was made through a nozzle with outlets 2 feet apart than when it was made with the standard nozzle, but was probably not so good as when it was made with the baffle nozzle. However, the nozzle with outlets 2 feet apart has several advantages over the baffle nozzle. It is simple, has

no moving parts, and can be moved in and out from under a tree without catching on the tree or on the tent.

The nozzle with outlets 2 feet apart was compared with the standard nozzle on the basis of the kill of the California red scale in four commercial fumigations. The comparisons were made with medium to large trees in three orange groves and one lemon grove. Ten or more trees were treated with each nozzle in each grove. Trees of about the same size were treated with each nozzle in the same throw of tents. The same vaporizer was used for both nozzles. A schedule of 20 cc. per unit was used in one grove, 22 cc. in another, and 24 cc. in the other two groves. Mortality counts were made on scale-infested fruits from each cardinal direction of the trees. The kills were more uniform on the trees to which the gas was applied with the special nozzle, but the average kill was no different from that obtained with the standard nozzle.

Propeller-Blower Applicator

The multivane blower applicator described by Fulton and Nelson (2) and the propeller-blower applicator described by Yust (5) were developed to give improved distribution of hydrocyanic acid in tent-covered citrus trees. After a long period of changes and tests, the distribution of gas with the propeller-blower applicator was studied in a series of special tests conducted on seven nights. On each night two lemon trees were treated with the propeller-blower applicator and with a standard vaporizer. Since short exposures were used, each tree was fumigated with each apparatus. Gas samples were taken from eight locations ½ minute and 2½ minutes after each release. The trees were relatively open and varied from small to large.

Several other field tests were made on orange and lemon trees in cooperation with commercial fumigators. The orange trees were large and moderately dense and the lemon trees were medium in size and dense with brush and foliage. The lower branches of the orange trees cleared the ground and the blower could be easily pushed under the tent, but the lemon trees had large low branches so that it was usually impossible to push the applicator through or under them. Gas samples were taken from four locations under each of four lemon trees and three orange trees treated with each applicator.

Table 3 shows that the propeller-blower applicator gave a much better initial distribution of the hydrocyanic acid than the vaporizer in both series of tests. However, distribution in the commercial tests was not so uniform as in the special tests, for which more open trees were used.

Mortality counts and population studies of the California red scale were made in groves treated by commercial fumigators with the two types of applicators. About the same degree of scale control was obtained with both applicators. Apparently the improvement in gas distribution was not sufficient to offset disadvantages introduced by the blower.

Table 3.—Distribution of hydrocyanic acid obtained with the standard vaporizer and the propeller-blower applicator

Applicator	Coefficient of variation in concentration (percent) at indicated interval after release			
	Special tests		Commercial tests	
	½ minute	2½ minutes	½ minute	2½ minutes
Vaporizer	56.7	23.6	111.8	60.1
Propeller-blower	25.4	12.0	41.9	16.1

The commercial fumigations brought out the following disadvantages in the propeller-blower applicator that were not apparent in prior experiments. (1) More strenuous work for the operator, (2) slower rate of fumigation, (3) more drift gas, (4) pulling the blower backwards, (5) difficulty in maneuvering the blower in rough ground, (6) tendency of the blower to catch in the foliage and tent, (7) injury to foliage in front of the machine by the hydrocyanic acid and the blower, and (8) tendency of gas concentrations to be lower with the blower. Fumigation with the blower was more strenuous and slower than with the vaporizer, because the machine was pushed under the tent and pulled backwards from tree to tree. The blower was pulled backwards to reduce the hazard presented by the drift gas being blown forward in the path of the operator. There was a tendency for the foliage and the tent to catch on the blower when it was shoved under the tree, although the machine was thoroughly screened. Concentrations were probably lower in trees with dense foliage near the ground, because the atomized hydrocyanic acid condensed on the foliage.

Summary

Field fumigations of citrus trees for control of the California red scale (*Aonidiella aurantii* (Mask.)) were made to determine whether more uniform distribution of hydrocyanic acid could be obtained by improving the standard vaporizers or their operation, or by developing an improved applicator. With the standard vaporizers the gas concentration was low on the side of the tree on which it was released and high on the opposite side, and was more variable when the foliage was dense than when it was thin.

Distribution of hydrocyanic acid with the vaporizer was improved (1) when half the gas was released from one side and half from the opposite side under the tree, (2) when a baffle was placed on the standard vapor-

izer nozzle to change the direction of the stream of hydrocyanic acid during part of the release period, and (3) when outlets 2 feet apart were provided on the vaporizer nozzle. A propeller-blower applicator gave much better distribution of hydrocyanic acid than a standard vaporizer.

Unfortunately, improved distribution of hydrocyanic acid did not result in improved kills of the California red scale under conditions of commercial operation, and the baffle nozzle and blower applicator were found to have serious operational disadvantages.

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